Physical and Optical Characteristics of Thin Layers

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LONG-TERM GOALS

The long-term goal of this project is to be able to predict radiative transfer in natural waters via the inherent optical properties given the biogeochemical nature of the particles and dissolved materials and the physical forcing applied to the water column. Conversely we want to be able to determine the inherent optical properties and the nature of the particulate and dissolved materials and their space-time structure from upwelling radiance spectra.

SCIENTIFIC OBJECTIVES

The scientific objectives of this effort are: 1) To experimentally determine the forcing and mixing conditions that characterize thin layers and their concomitant Inherent and Apparent Optical Properties (IOP and AOP) ; 2) To experimentally and numerically test the backscattering-independent algorithm (Barnard et al.,1998b) to obtain the absorption coefficient from the upwelling radiance spectrum; and 3) To experimentally test our remote sensing model of fronts and internal waves (Zaneveld et al., 1998).

APPROACH

Our approach is to first develop the theoretical and experimental tools necessary to achieve the objectives. A model relating the dependence of the upwelling radiance spectrum on the vertical structure of the IOP as related to the physical structure (i.e. thin layers, fronts, and internal waves) was developed by Zaneveld and Pegau (1998). Numerical models relating the reflectance to thin layer characteristics have been developed (Petrenko et al., 1998). Models relating the IOP globally and to the remotely sensed reflectance have been developed by Barnard, Zaneveld, and Pegau (Barnard 1998a, 1998b) as well. These models provide the hypotheses to be tested during the field program. Instrumentation and calibration procedures have been and continue to be developed in order to measure the appropriate IOP and AOP accurately (Zaneveld et al. 1992, 1994, Pegau et al. 1993, 1995, 1996 etc.)

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Zaneveld, Barnard and Boss participated in two field experiments during 1998. Our approach was to measure spectral absorption and attenuation for dissolved and particulate materials and to measure the downwelling irradiance and upwelling radiance spectra as a function of depth, location within the Sound, tidal stage etc. This work was carried out in conjunction with other researchers, who, during the first experiment, measured the same parameters in addition to biogeochemical parameters from a moored barge moored within the Sound. Aircraft overflights using a spectral radiometer were carried out by the Naval Research Lab. (Dr. Curt Davis) during the second experiment.

WORK COMPLETED

A two-flow radiative transfer approach was used to derive a theoretical model for the remotely sensed reflectance of thin layers, internal waves, and fronts. This work was published in Oceanography (Zaneveld and Pegau, 1998).

We completed a numerical study of the influence of the vertical distribution of the absorption and backscattering coefficients on the remotely sensed reflectance. This work was published in Oceanography (Petrenko et al., 1998).

We analyzed the global relationships between inherent optical properties using data from eight previous cruises. This work was published in the Journal of Geophysical Research (Barnard et al., 1998a).

We developed an inversion method to obtain the absorption coefficient from the remotely sensed reflectance spectrum and used it to demonstrate closure between in situ IOP and AOP measurements. This work has been submitted to Applied Optics (Barnard et al. 1998b).

Within the context of the Thin Layers Experiment we carried out measurements on a chartered vessel between 6/8/98 and 6/18/98 in East Sound, WA. Vertical profiles of the inherent optical properties and the physical characteristics were made from the Slow Decent Rate Optical Platform (SlowDROP). The package containted a hyperspectral (100 wavelengths) absorption and beam attenaution meters (WET Labs, HiStar), two nine wavelength absorption and beam attenuation meter (WET Labs, Inc. ac-9), a SeaBird CTD (SBE25), a chlorophyll fluorometer (WET Labs, Inc. WetStar), and a backscattering meter (WET Labs). A Satlantic SPMR profiling and reference radiometer system was used to collect profiles of the downwelling irradiance and upwelling radiance at 7 wavelengths. Atmospheric optical thickness measurements were measured using a Microtops sunphotometer. The ac-9 and Hi-STAR were callibrated on a daily against ‘pure’ water (Barnstead infinity). We performed several cross-calibrations by sampling simultaneously with both Dr Cowles’ (O.S.U.) and Dr. Donaghay’s (U.R.I.) groups.

We collected data both while anchored and distributed spatially in order to quantify temporal and spatial variability in the Sound. During one day we sampled for 24hrs to resolve the daily cycle. The data are currently being processed to assure its quality. They will be available to all participating P.I.’s on our web site (http://photon.oce.orst.edu) in the near future.

A. Barnard participated in an ONR sponsored experiment during July 28 through August 11, 1998 aboard the R/V Barnes in East Sound, Orcas Island, WA. This experiment was performed in coordination with Dr. Curt Davis at the Naval Research Laboratory, ONR Washington, D.C. Our

role in this experiment was to examine the fine scale vertical structure of the optical properties, and to provide inherent optical property (IOP) and apparent optical property (AOP) data to be used as a validation data set for the Navy's hyperspectral remote sensing imager. Vertical profiles of the inherent optical properties and the physical characteristics were made from the SlowDROP described above, except with two HiStars and one ac-9. A Satlantic SPMR profiling and reference radiometer system was used to collect profiles of the downwelling irradiance and upwelling radiance at 7 wavelengths. Atmospheric optical thickness measurements were measured using a Microtops sunphotometer. A total of 127 SlowDROP and 140 Satlantic SPMR profiles were taken. The AOP profiles were typically taken within 5-15 minutes of an IOP profile. Three main stations were typically occupied each day, stations 1A, 1B and 1C, transecting from east to west from Olga, Orcas Island to the sill near the mouth of East Sound. We also sampled various other locations during the cruise in coordination with other groups participating in the experiment. We are currently processing these data and will provide these data to Dr. Davis' group.

High-frequency hydrographic, spectral absorption, attenuation and fluorescence profiles were obtained from two platforms, a mooring and a ship, at East Sound, WA, as part of the Thin Layer Experiment. The spectral absorption and fluorescence of the total and dissolved components were measured so that the contribution by particulate matter could be computed. The spatial scales governing the distribution hydrographic and bio-optical properties are computed in order to elucidate the degree of coherence between them. We then examined the respective contribution of these scales to the observed optical variability. The temporal variability in optical parameters on isopycnals was calculated in order to provide the rates of processes affecting their distribution. The results have been interpreted and contrasted with processes that are known to contribute and control the distribution of physical, biological, and optical variability (Boss et al., 1998).

Using a near-forward scattering device based on a Hartmann array and a modified turbulence test chamber a previously developed model of the relationship between turbulent parameters and near-forward scattering (Bogucki et al., 1996) was successfully verified at the Los Alamos National Laboratory in conjunction with researchers from the University of New Mexico.

RESULTS

We showed that the vertical structure of b_b/a determines the remotely sensed reflectance at the surface (figure 1). If this parameter is constant with depth (optical homogeneity), even though b_b and a vary with depth, such depth structure will not change the remotely sensed reflectance. We showed that if b_b/a varies with depth due to thin layers, internal waves or fronts, features of the physical structure can be derived using optical remote sensing (Zaneveld and Pegau, 1998).

We showed that, depending on the vertical structure of the IOP, a thin layer can increase or decrease the reflectance of an ocean with a thin layer relative to that of one without. The thicker the layer and the shallower it is and the greater its b_b/a deviation from the surrounding waters, the larger its influence on the reflectance at the surface (Petrenko et al., 1998)

We demonstrated that on a global scale the relationship between $a(\lambda)$ and a(488) for particles and CDOM, but also for total absorption can be statistically described by a straight line (figure 2). This does not imply that the shape of the spectrum is constant. That is only the case if the intercept is zero. These relationships show that excellent (about 0.005 m^{-1}) inter-cruise calibration exists (Barnard et al. 1998a).

Closure for in situ observations of the IOP and AOP was demonstrated using a backscattering independent algorithm that relates the reflectance at three wavelengths to the absorption coefficient at three wavelengths (Barnard et al., 1998b). In this paper we also show that the absorption coefficient at 488 nm can be retrieved when the reflectances at three wavelengths are known.

We have further established the importance of turbulence in the modification of the inherent optical properties. We developed a numerical model that allows the prediction of the forward scattering function when the turbulent parameters are known (Bogucki et al., 1998). Enhanced forward scattering affects visibility as well as the inversion of the forward scattering function to obtain particle size distributions.

IMPACT/APPLICATIONS

There have been widespread applications of our ac-9 calibration procedures including the temperature dependence of absorption by pure water (Pegau et al. 1997). These procedures continue to be refined for the HiStar devices.

The theoretical work (Zaneveld and Pegau, 1998; Petrenko et al., 1998) will be used in inverting remotely sensed reflectance to obtain vertical structure of the IOP and so to infer physical structure.

Having demonstrated closure between IOP and AOP in situ (Barnard et al., 1998b), in situ observations of IOP combined with inversions show that IOP can be used to vicariously calibrate satellite radiance sensors. This is important as atmospheric corrections, especially near shore still are problematic.

In turbulent regimes, especially inlets, near shore in the wave regime, and in near-surface reefs, the turbulence will cause visibility to be degraded. This is now being modeled.

The data from the Thin Layers Experiments is being shared with other researchers to examine the effect of physical forcing on the generation and maintenance of thin optical/biological layers. The data is also being used to examine algorithms for the inversion of remotely sensed radiance.

TRANSITIONS

Instrumentation and calibration procedures developed at O.S.U. or in cooperation are widely used for the accurate in situ observation of the spectral absorption, scattering and attenuation coefficients.

Theoretical efforts and analyses carried out using ONR core funding have led to follow-on studies by other researchers and are frequently cited.

We have cooperated frequently with the Naval Research Laboratory (Drs. C. Davis and A. Weidemann) in the measurement and interpretation of the IOP as related to remote sensing and dynamics.

RELATED PROJECTS

Coastal Mixing and Optics- ONR: Analytical and numerical methods developed under the grant described here are used in the interpretation of data collected during CM&O.

SIMBIOS-NASA: The remote sensing algorithm and instrumentation techniques and calibration are used to interpret data collected under the SIMBIOS program.

SeaWiFS-NASA: This project co-sponsored the development of the inversion algorithm to obtain absorption from remotely sensed reflectance.

REFERENCES

A.H.Barnard, W.S.Pegau, and J.R.V.Zaneveld, Global relationships of the inherent optical properties of the oceans. *J. Geophys. Res.* **103**: 24,955- 24,968. (1998a)

A.H.Barnard, J.R.V.Zaneveld, and W.S.Pegau, Remotely sensed reflectance and the absorption coefficient: closure and inversion. Submitted to Applied Optics.(1998b)

D.Bogucki, J.A.Domaradski, D.Stramski, and J.R.V.Zaneveld., Near-forward scattering on turbulence- comparison with scattering on oceanic particles. *Applied Optics* **37**, 4669-4677. (1998)

E. Boss, M.S.Twardowski, A.H.Barnard, W.S. Pegau, Conservative and non-conservative behavior of optical properties in an Inlet. Sumitted to ASLO.

W.S.Pegau, D.Grey, and J.R.V.Zaneveld , Absorption of visible and near-infrared light in water: the dependence on temperature and salinity.*Applied Optics.* **36,** 6035- 6046. (1997)

W.S.Pegau, J.R.V.Zaneveld, and K.J.Voss, Towards closure of the inherent optical properties.*J.Geophys Res.* **100** (C7), 13,193-13,200. (1995)

W.S.Pegau and J. R. V. Zaneveld, Temperature dependent absorption of water in the red and near infrared portions of the spectrum, *Limnol. Oceanogr.* **38**, 188-192 (1993)

A.A.Petrenko, J.R.V.Zaneveld, W.S.Pegau, A.H.Barnard, and C.D. Mobley, Effects of a thin layer on reflectance and remote-sensing reflectance. *Oceanography*. **11,** 48-50.(1998)

J. R. V.Zaneveld, J. C. Kitchen, A. Bricaud and C. Moore, Analysis of *in situ* spectral absorption meter data. *Ocean Optics XI*, G. D. Gilbert, Ed., Proc. SPIE **1750**, 187-200 (1992)

J.R.V.Zaneveld and W.S.Pegau , A model for the reflectance of thin layers, fronts, and internal waves and its inversion. *Oceanography*. **11,** 44-47.(1998)

J.R.V.Zaneveld, A theoretical derivation of the dependence of the remotely sensed reflectance on the inherent optical properties. *J.Geophys Res.* **100** (C7), 13,135-13,142.(1995)

J.R.V.Zaneveld, J.C.Kitchen, and C.C.Moore, Scattering error correction of reflecting tube absorption meters.*Ocean Optics XII*, S.Ackleson, Ed., Proc. SPIE Vol. **2258**, 44-55 (1994)

http://photon.oce.orst.edu , OSU Ocean Optics home page;
ftp://photon.oce.orst.edu , Anonymous ftp site

$$R_{rs}(0^-) = \sum_{n=1}^{N} R_{rs\,n} \; H_n$$

$$H_n = [1 - \exp(-2K_n \Delta z_n)] \exp\left(-\sum_{i=1}^{n-1} 2K_i \, \Delta z_i\right)$$

$$\exp(-2K_n \Delta z_n) = [L_{un} \, E_{dn}] / [L_{un-1} \, E_{dn-1}]$$

$$H_n = \frac{L_{un-1} \, E_{dn-1} - L_{un} \, E_{dn}}{L_{u0} \, E_{d0}} \; .$$

Each layer is assumed to be homogeneous, and would apply if the layer was infinitely deep:

$$R_{rs\,n} = f \, b_{bn} / a_n$$

so that substitution into above yields:

$$R_{rs}(0^-) = f \sum_{n=1}^{N} (b_{bn} / a_n) \; H_n.$$

$$\sum_{n=1}^{N} H_n = 1 - \exp\left(-\sum_{i=1}^{N} 2K_i \, \Delta z_i\right) = 1,$$

since $\sum_{i=1}^{N} \Delta z_i =$ and the K_i are non-zero.

$R_{rs}(0^-)$ = Remote sensing reflectance just below the surface
$R_{rs\,n}$ = reflectance of a homogeneous ocean with the same optical properties as the nth layer
Δz_n = the thickness of the nth layer
K_n = the attenuation coefficient of the light going downwards and upwards in the nth layer
L_{un} = upwelling radiance, at the bottom of the nth layer
E_{dn} = the downwelling irradiance, at the bottom of the nth layer
Subscripts 0 refer to values immediately below the water surface

Figure 1 - Layer model equations to determine the remotely sensed reflectance from the vertical structure of the backscattering to absorption ratio.

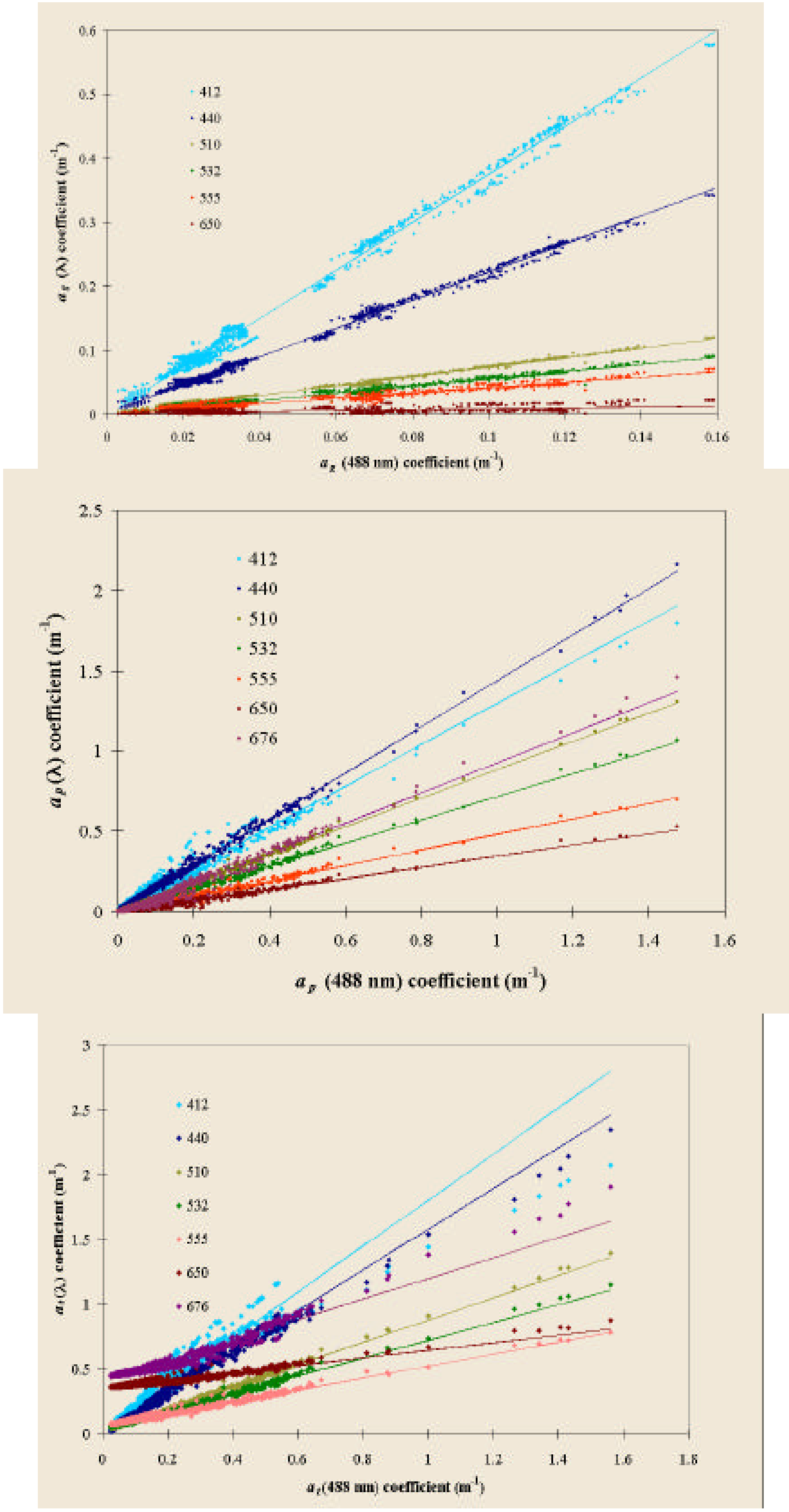

Figure 2 - Absorption (dissolved, top; particulate, middle; total, bottom) coefficient relationships as a function of the absorption coefficient at 488 nm.